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Estimating and Projecting Impervious Cover in the Southeastern United States

by

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Effective storm water management practices implemented in a watershed to control runoff volumes, flow rates and pollutant concentration can partially mitigate the impacts of urbanization and increased imperviousness. Development practices that reduce effective impervious area (EIA) and include other strategies to protect water quality are more effective and less costly than remedial restoration efforts (Nichols, et al. 1999). EIA is that portion of the total impervious area (TIA) that is directly connected to the stream drainage system. The EIA includes streets, driveways, sidewalks adjacent to curbed streets, parking lots, and rooftops hydraulically connected to the curb or storm sewer system. Empirical relationships between EIA and TIA have been developed (Sutherland 1995). Rainfall on impervious areas that are not directly connected hydraulically to the drainage collection system does not always result in direct runoff and is not as damaging to the biotic integrity of the stream system.

Parcel based analyses of hydrologic and other impacts of impervious area are needed to inform effective land use policies and local development regulations. Regression modeling using six important aspects of parcel and street network design explained roughly 77% of residential impervious cover variation in the Madison, Wisconsin area. This work pointed to potentially effective policies to reduce imperviousness through zoning considerations such as lot size, frontage, and front yard setbacks; through street and subdivision design practices such as block size and intersection density; and through retrofit of existing residential driveways (~20% of impervious area of parcels) with porous paving materials over time as resurfacing is needed (Stone 2004).

The change from a watershed with relatively pristine streams to one with significant symptoms of degradation can occur rapidly in high growth urban areas. Often this occurs before an awareness by local planners develops on the need to consciously manage storm water impacts. State storm water control mandates are often set well above the levels where instream biotic degradation occurs. Impervious area estimates and projections are a potentially effective tool for highlighting areas that are at-risk for aquatic resources degradation or where stream system integrity is likely to decline in the near future if effective planning and management programs are not implemented. These estimates and projections can also guide the selection of monitoring locations by state and regional EPA officials, focus educational efforts in at-risk areas, and aid wide-area planning.

1.1 Stream Biotic Response to Impervious Cover

Recent research has consistently shown strong relationships between the percentage of impervious cover in a watershed and the health of the receiving stream. Booth and Jackson (1994) suggest that 10% impervious watershed area "typically yields demonstrable loss of aquatic system function," and that lower levels may be significant to sensitive waters. In a review of research on impervious cover, Schueler (1994) concluded that, despite a range of different criteria for stream health, use of widely varying methods and a range of geographic conditions, stream degradation consistently occurred at relatively low levels of imperviousness (10% or greater). May, et al. (1997) found that indicators of stream health in the Puget Sound Lowlands declined most rapidly from 5 to 10% impervious cover. A recent survey of Maryland streams (Boward, et al. 1999) found that brook trout (Salvelinus fontinalis), a species very sensitive to water temperature, were not present in any streams where the watershed was greater than 2% impervious cover.

Fish IBI results for Ridge and Valley streams indicated poor or very poor fish communities for catchments with greater than 7% urban land use (Snyder, et al. 2003). Ohio urban gradient stream sites - excluding sites with allied stresses such as combined sewer overflows, waste water treatment plants, sewer line problems and other habitat alterations -

showed significant IBI declines with urban area greater than 13.8% and failed to meet Clean Water Act goals where urban area exceeded 27.1% (Miltner, et al. 2004). Extensive loss of mussel species (50 to 70%) occurred in Georgia streams experiencing impervious area expansion (Gillies, et al. 2003). Tidal creek ecosystems in South Carolina experienced adverse physical and chemical changes (hydrology, salinity, sediment, chemical contamination and fecal coliform loading) above 10 to 20% imperviousness, with significant biological changes above 20 to 30% impervious area (Holland, et al. 2004). For southeastern Wisconsin streams, fish communities declined sharply between 8 to 12% connected imperviousness and were consistently poor above 12% impervious area (Wang, et al. 2001). Evaluation of 245 sites with biological data in Montgomery County, Maryland required less than 10% impervious and greater than 60% riparian tree cover to attain a stream health rating of good (Goetz, et al. 2003).

Scientists recognize that fish assemblages in developed watersheds are affected primarily by nonpoint source anthropogenic stressors that result from land use development (Williams, et al. 1989; Richter, et al. 1997; Wilcove, et al. 1998). Alteration of hydrologic regimes in terms of the amount and variability of flow affect all aspects of fish life history (e.g., Allan 1995). Sedimentation can increase fish movement, interfere with fish feeding by reducing reactive distance for sight-feeders and lower the abundance of insects available as food, and impair reproduction of fishes with specific spawning habitat requirements (Newcombe and MacDonald 1991; Bergstedt and Bergersen 1997). Habitat destruction can isolate patches of suitable habitat within a stream which reduces species' survival. Habitat destruction also changes the natural mosaic of habitat conditions, thereby altering natural fish movement and migration patterns (Reeves, et al. 1995).

This wide variety of stream response to imperviousness may likely be due to local slope, soils, geology, land and storm water management practices and other factors. For example, higher gradient sites in the Ridge and Valley show larger decreases in fish IBI with increasing imperviousness than do lower gradient sites (Snyder, et al. 2003). Absent more specific local models, Schueler's (1994) three imperviousness classes of impact provide a useful initial guide to stream quality in the Southeastern United States:

Sensitive streams have 0 to10% imperviousness and typically have good water quality, good habitat structure, and diverse biological communities if riparian zones are intact and other stresses are absent.

Impacted streams have 10 to 25% imperviousness and show clear signs of degradation and only fair in-stream biological diversity.

Non-supporting streams have >25% impervious, a highly unstable channel and poor biological condition supporting only pollutant-tolerant fish and insects.

A more extensive and updated review of this classification of impact corroborated these original conclusions (Center for Watershed Protection 2003). While impervious cover alone is not the sole causative agent for the decline of aquatic health in urbanizing areas (Miltner, et al. 2004), it contributes significantly to the decline and appears to serve as an integrative screening indicator of urban hydrologic stress (Arnold and Gibbons, 1996).

While complete descriptions of the range of aquatic responses to imperviousness are not available for all areas of the Southeastern United States, extensive biological sampling of benthic macro invertebrates by the North Carolina Division of Water Quality covering the wide gradient of impervious area throughout the Southern Piedmont ecological region (Griffith, et al. 2002) provides the best existing data to begin building such relationships. Cursory descriptive examination of a portion of this data allows us to glimpse the potential for using existing and new data to construct robust relationships valid for the entire Southeast.

Benthic data for over 300 Piedmont sites were kindly provided by Trish MacPherson of the North Carolina Division of Water Quality (NCDWQ), along with point watersheds delineated for those sites graciously shared by Dr. Halil Cakir and Dr. James Gilliam of North Carolina State University. Their detailed, rigorous statistical examination of this data is currently in preparation.

Figure 1.1 maps these North Carolina Piedmont watersheds by impervious class, in the context of satellite based land use/land cover for that area. For 159 of these sites with non-overlapping watersheds, Multiple Data Source (MDS - described in Section 3.3 of this report) impervious area estimates were produced. The MDS imperviousness of these watersheds ranges from 1% to 60%.

Figure 1.2 depicts simple box plots of the benthic biological condition response of streams to increasing impervious area (using both 5% and 10% ranges) for that gradient of Piedmont sites based on the North Carolina Biotic Index (NCBI), a tolerance based metric used for benthic community assessments and aquatic life use support determinations by NCDWQ (North Carolina Department of Environment and Natural Resources 2003). Assuming NCBI scores above 6.54 (worse than "fair" on the state's scale of: excellent, good, good-fair, fair, fair-poor and poor) indicate degraded conditions, progressively greater fractions of degraded sites are evident as impervious area increases. For watershed Total Impervious Area (TIA) greater than 10%: 62% (32/52) of sites are degraded; for TIA > 15%: 78% (25/32) of sites are degraded; for TIA > 20%: 83% (19/23) of sites are degraded; and for TIA > 30%: 91% (10/11) of sites are degraded. In contrast, for watersheds with TIA<10%: 10% (11/107) of sites were degraded. The figure also provides percentages and numbers of sites for individual 5% and 10% ranges of impervious area.

1.2 Using Impervious Cover as a Regional Indicator

Impervious cover when used as an indicator of stream health is typically presented as a percentage of the total land in an area that contains the impervious surfaces, or percent total impervious area (%TIA). Several challenges exist in using impervious cover as a regional indicator. First is simply defining impervious cover since it is not a single, unambiguous quantity. Generally, paved surfaces and buildings fall unambiguously under the definition of impervious surfaces. Ambiguity can exist, however, even for these categories since there is now a pervious asphalt paving material that allows some infiltration. Other areas, such as dirt roads, railroad yards and construction areas that may not be coated with manmade impervious materials, are in many instances so heavily compacted as to be functionally impervious. Another important distinction concerning impervious cover and its impact on stream health is between connected and disconnected impervious surfaces. Connected impervious surfaces are networked impervious surfaces (parking lots, roads, sidewalks, etc.) that are physically interconnected and eventually flow directly into stream systems via storm sewers, ditches and culverts. Disconnected impervious surfaces, such as rooftops, often deposit runoff onto vegetated pervious areas. The water from these disconnected impervious surfaces flows through the subsurface before reaching stream channel networks, mitigating some of the negative impact on the receiving waters.